DOCUMENT RESUME

ED 286 758 SE 048 598

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TITLE	Generation of Spontaneous Analogies by Students Solving Science Problems.
SPONS AGENCY	National Science Foundation, Washington, D.C.
PUB DATE	2 Jan 87
GRANT	MDR-8470579
NOTE	14p.; Paper presented at the International Conference on Thinking (3rd, Honolulu, HI, January 4-8, 1987).
PUB TYPE	Reports - Research/Technical (143) -- Speeches/Conference Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Cognitive Structures; *College Science; *Concept Formation; Creative Thinking; Higher Education; Learning Processes; *Learning Strategies; Misconceptions; *Physics; *Problem Solving; Science Education; *Science Instruction; Scientific Concepts
IDENTIFIERS	*Analogies

ABSTRACT

In this study 34 spontaneous analogies produced by 16 college freshmen while solving qualitative physics problems are analyzed. A number of the analogies were invalid in the sense that they led to an incorrect answer from the physicist's point of view. However, many were valid, and a few were powerful in the sense that they seemed not only to help the student solve the problem, but led to generalizations indicating that some conceptual change was taking place. Some of the effective analogies have also been observed in the solutions used by expert scientists and mathematicians. These findings support the position that many creative reasoning processes are ordinary thinking processes used with special purposes in mind, not unanalyzable acts of "genius." This suggests that analogies are an intuitive form of reasoning that could be tapped or taken advantage of in instruction to a greater extent than is currently done. (Author/TW)

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GENERATION OF SPONTANEOUS ANALOGIES BY STUDENTS SOLVING SCIENCE PROBLEMS

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Paper presented at the Third International Conference on Thinking, 1/6/87.

Research reported in this paper was supported by a grant from the National Science Foundation # MDR8470579.

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ABSTRACT

Thirty-four spontaneous analogies produced by 16 college freshmen while solving qualitative physics problems are analyzed. A number of the analogies were invalid in the sense that they led to an incorrect answer from the physicist's point of view. However, many were valid, and a few were quite powerful in the sense that they seemed not only to help the student solve the problem but led to generalizations indicating that some conceptual change was taking place. These are processes that have also been observed in the solutions of expert scientists and mathematicians. These findings support the position of Perkins (1981) that many creative reasoning processes are ordinary thinking processes used with special purposes in mind, not unanalyzable acts of "genius". This suggests that analogies are an intuitive form of reasoning that could be tapped or taken advantage of in instruction to a greater extent than is currently done.

GENERATION OF SPONTANEOUS ANALOGIES BY STUDENTS SOLVING SCIENCE PROBLEMS

Snow (1961) described the gap between the technological and humanistic orientations in modern society as a gap between "two cultures" and viewed many modern problems as arising from the lack of communication between them. It is possible that a similar gap exists between the experts who teach introductory college science and the naive student attempting to comprehend a scientific discipline for the first time.

Recent data on persistent preconceptions in physics, for example, (Clement, 1982, McCloskey, 1983) show that students bring preconceptions with them to class which resist modification and which are powerful enough to prevent the student from assimilating new material.

In addition to using a new vocabulary and a qualitatively different set of concepts and beliefs, it is worth considering whether the expert may also use a different set of reasoning processes from the naive student. This paper looks in particular at analogical reasoning, a component of scientific thinking in experts, and asks whether students can use this reasoning process as well. The answer to this question should speak to the larger

issue of the width of the gap between the "two cultures" of students and experts.

The question becomes more important when we note that analogies have long been advocated as a powerful tool in teaching. There is evidence that experts can use analogical reasoning to help them resolve conceptual difficulties during problem solving (Clement, 1981). We suspect that analogical reasoning can also be used to help students resolve their conceptual difficulties. But we suspect that they need to do the reasoning, not just memorize the two connected sides of an analogy, in order to increase their understanding. Thus, it is an important question as to whether students can reason analogically or whether this is a process that is part of the private repertoire of a privileged group of experts.

Use of Analogies by Experts

Evidence that experts use analogical reasoning comes from several types of sources including philosophical studies (Hesse, 1966) and historical studies (Dreistadt, 1968). Knorr (1981) is attempting to study scientific method by observing and interviewing scientists in the laboratory as they work on innovative research projects. One of Knorr's major conclusions is that the use of analogies by scientists is a major source of innovation in their work. Knorr's interviews with scientists

indicate that analogies can suggest hypotheses for new theoretical models as well as new experimental and industrial techniques.

Another source of evidence for expert use of analogies comes from thinking aloud problem solving interviews. Clement (1981, to appear) observed the use of analogies by experts in several physics and mathematics problems. One problem asked whether a spring with wide coils stretches more than a spring with narrow coils (assuming they are made of the same wire with the same thickness and the same number of coils). For this problem ten experts in technical fields generated 39 analogies altogether. Thus there is evidence from several different sources that analogical reasoning is an important component of scientific thinking.

Use of Analogies by Students

In the remainder of this paper, I discuss responses to a set of qualitative physics problems given to a group of 16 freshmen engineering majors who had not taken college physics. The students were asked to think aloud as they solved problems in a clinical interview setting. Each of the students worked on 6 problems. Tapes of the interviews were examined in order to determine whether they had spontaneously generated any analogies during their solution. A spontaneous analogy occurs when the subject, without provocation, refers to a different situation B that he believes may be structurally similar to the origi nal problem situation A. (See Table 1)

In fact, a large number of analogies were generated in solving the problems. Of the 96 problem solutions, 24 contained analogies. However, many individual problem solutions contained several analogies, so that 59 analogies were generated in all.

We were surprised at the relatively high number of analogies produced, given the fact that informal arguments and divergent thinking on the part of the students are rarely encouraged in secondary schools. Some of the observed analogies were vague and not pursued at length, but at least 34 of them were significant in

One goal of this exploratory study is to suggest some basic categories for describing different types of analogies. 6

the sense of being both fairly clearly articulated and used by the students to generate or add support to their problem solutions.

Types of Spontaneous Analogies Generated

Further analysis of the data concentrated on these 34 significant analogies occurring in 18 of the solutions. A brief summary of the observations made from this data base is given here. (See Table 2)

(1) Personal vs physical analogies. Given the fact that the problems used were qualitative physics problems, one might assume that the analogies would tend to be physical rather than personal in nature. However, approximately half of the analogies were personal analogies referring to some sort of body action. This indicates a preference on the part of many students for anthropomorphic explanations. For example, S9, in solving a problem about the speed of an arrow shot backwards from a moving chariot, says: "If you were in a train that was starting up...and you run to the back of the train, the train's running underneath you, but if you run at the same speed as the train, then, uh, you're going nowhere."

(2) Invented vs factual analogies. The large majority of analogies in the sample appear to be based on a fact that the student has observed or believes from authority. Nevertheless, at least six of the cases were so novel that they were clearly new

inventions, showing that students are sometimes capable of producing "custom-designed" thought experiments spontaneously.

(3) Generating analogies with and without a principle. In a minority of the instances cited, students referred to a general principle before generating an analogous case. It seems likely that analogies are more often used when the subject lacks an appropriate formal principle to apply.

(4) Individual differences. There was wide variation in the number of analogies produced by different individuals. A few students produced none at all while one student produced 13 of the 34 significant analogies studied.

(5) Predictive Validity. Six of the thirty-four significant analogies were invalid in the sense that they led to an incorrect answer from the physicist's point of view. However, possibly a larger proportion of the original entire sample of 59 analogies would be judged invalid. A few analogies were fairly powerful in the sense that they seemed not only to help the student solve the problem but led to generalizations indicating that some conceptual change was taking place.

(6) Analogy evaluation. Several students were able to criticize and evaluate their analogies after they were constructed. However, many other students did not give evidence for evaluating the appropriateness of their analogies, suggesting

that this may be an area where analogical reasoning needs to be improved by instruction.

(7) Progressive refinement. At least 3 of the students generated a sequence of several analogies to solve a problem. In producing these sequences, these students demonstrated an ability to progressively refine their explanations by criticizing and improving the first analogies they produced.

Conclusion

A number of recent research studies have concentrated on examining differences between experts and novices. In the present study however, the emphasis has been on examining a way in which experts and novices are alike-- both can generate creative solutions by analogy during problem solving. Of course we would hypothesize that there are differences in this area as well. We have shown that students generate analogies just as experts do. But it is unlikely that they would produce appropriate and successful analogies as often. And students are probably less likely than experts to criticize an analogy.

However, in considering our earlier general question about the size of the gap between experts and students we can still conclude that the ability to generate spontaneous analogies is shared by many experts and students. Although it can be one of the most sophisticated tools of scientific problem solving, spontaneous analogy generation can occur in the problem solving of

rather inexperienced students. Rather than showing that students made use of analogies that were presented to them, the examples in this study show that students actually formed analogies spontaneously in thinking aloud problem solutions. A few of the students even generated chains of several analogies and to constructed custom-designed thought experiments.

These are creative problem solving processes that have also been observed in the solutions of expert scientists and mathematicians (Clement, 1981, 1986, and to appear). These findings support the position of Perkins (1981) that many creative reasoning processes are ordinary thinking processes used with special purposes in mind, not unanalyzable acts of "genius". This suggests that analogies are an intuitive form of reasoning that could be tapped or taken advantage of in instruction to a greater extent than is currently done.

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ANALOGIES GENERATED

SUBJECTS	N = 16	
PROBLEMS SOLVED BY EACH	6	
PROBLEM SOLUTIONS	96	
SOLUTIONS CONTAINING ONE OR MORE ANALOGIES	24	(25%)
SOLUTIONS CONTAINING ONE OR MORE SIGNIFICANT, ARTICULATED ANALOGIES	18	(19%)
TOTAL NUMBER OF ANALOGIES GENERATED	59	
NUMBER OF SIGNIFICANT, ARTICULATED ANALOGIES	34	

Table 1

N = 34 ARTICUALTE ANALOGIES

CORRECT PREDICTION	28	(82%)
PERSONAL (VS. PHYSICAL)	18	(53%)
INVENTED (VS. FACTUAL)	6	(18%)
EVALUATED VALIDITY	5	(15%)
SUCCESSIVELY REFINED SERIES	3 GROUPS INVOLVING 11 ANALOGIES	
NEGATIVE ANALOGIES	4	(12%)

Table 2